TITLE: Fabrication and Magnetic Properties of 2D Arrays of Nanoparticles

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Fabrication and magnetic properties of 2D arrays of nanoparticles

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Several procedures can be chosen to create structures consisting of nanosized particles: chemical decomposition with the STM tip [1], self-organizing deposition on the crystal surfaces, the laser interference irradiation of solid mixture films [2] etc. However, till now electron-beam lithography remains one of the basic technique for the fabrication of ultrasmall structures, because only e-beam lithography ensures controllable dimensions, shape and position of particles. In specific cases using conventional processing with the positive resist poly(methyl methacrylate) (PMMA) it is possible to fabricate the structure with features less than 10 nm [3]. Unfortunately the large sizes of PMMA molecules (up to 100 nm) reduce the reproducibility of nanostructures dimensions and are severely limit an assortment of objects, that can to make by this manner. The small size of C_{60} molecules and the ability of fullerides to modify their physical and chemical properties under exposure to photon irradiation or electrons [4, 5] make it possible to use this material for high resolution nanofabrication. In the present paper we demonstrate the capabilities e-beam lithography with fullerens on an example of creation of two-dimensional periodical systems of nanosizes magnetic particles (nanomagnets). The main steps of the procedure for manufacture permalloy nanoparticles are thin films deposition, exposure by e-beam, development and two-stage etching. The choice of Ni_3Fe in this study has been dictated by magnetic experiment requirements, and it was discussed in [6]. We have used double-layer mask containing the C_{60} film as a sensitive layer and Ti film as a transmitting layer. Permalloy and Ti films have been prepared by pulse laser evaporation on the substrate at room temperature. Fulleride films were deposited by sublimation of a C_{60} powder (purity is 0.98, synthesised in ICMOC RAS, N. Novgorod) at temperature 350 °C in vertical reactor with hot walls and supplied with cooling holder for the substrate. The thickness of magnetic layers was varied from 20 to 70 nm due to magnetic experiments requirements. The thickness of masking films was 20 nm for the C_{60} layer and 30 nm for Ti film.

The fullerides were patterned in the JEM-2000EX electron microscope with scanning electron microscopy (SEM) mode and by 200 kV e-beam, which diameter was it is possible to change from 10 nm and over. Accordingly results in Ref. [5] the threshold of sensitivity the fulleride is about 0.01 C/cm^2, we have got one the same order of value in our experiments. Usually the doses for practical usage were 0.05 ... 0.1 C/cm^2, because it assured the reproducibility and uniformity of patterns sizes. Electron beam irradiation of C_{60} films reduces the solubility of fullerenes in organic solvents. The most likely reasons of changes of the solubility are electron induced polymerization C_{60} molecules accompanied partially graphitization ones [5, 7]. Exposed samples were developed in the toluene during 1 min, and then patterns were transferred into the Ti layer by plasma etching with CF_2Cl_2 atmosphere. The ended step of fabrication the magnetic particles is the Ar^+ ion milling of Ni_3Fe films, using this double-layered mask. By carefully monitoring the elemental composition of samples by means EDS qualitative microanalysis and checking up the morphology of particles by SEM, we can better detect the end points of plasma etching and ion milling

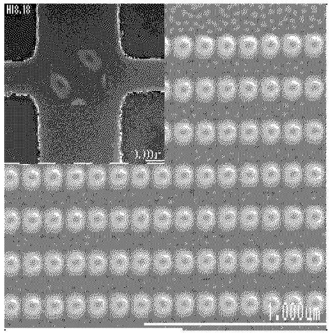

Fig. 1. SEM microphotography array of magnetic nanoparticles, top view. On an insert in the upper left corner of the figure array of magnetic nanoparticles with rectangular lattice on the Hall magnetometer (are seen Moire patterns between a lattice and raster of SEM).

processes. However, usually we have done some overmilling at the last step, to prevent presence any magnetic substance between the particles we make. Some SEM images of arrays of ferromagnetic particles are present at Fig. 1. The real shape of ferromagnetic core is a disc, which thickness equals the thickness of initial permalloy film, and it is a small part (approximately one third) of the visible height of a particle on the microphotograph. Also it is possible to fabricate magnetic columns by this procedure, but we didn't tried to create ones with aspect ratios more than 3:1, when diameters not exceeded 20 nm.

The smallest particle's diameter was about 10 nm, we have prepared by this method, and the distance between boundaries of particles was the same value. Moreover, we believe, that such ultrasmall size of magnet isn't the limit of this technique. Really, the main factor determining the ability of lithography is the resolution of resist. Using C_{60} we found, that the patterns by diameter less than 10 nm and the minimal distance between them 5–6 nm can be obtained in reproduced manner. However the observation, microphotography and correct measurements sizes of this kind objects is the special metrological task, which to us for the present did not uniquely to be decided.

The measurements of the magnetic properties were provide using the commercial Hall magnetometer. Difference scheme, consisting of two semiconductor (InSb) Hall sensors with common potentional contacts and independent current contacts was used [ ]. The system of particles investigated was formed in the working zone of one of the sensors (Fig. 1).

As the used method allows to measure only the z-component of the magnetization, we provide our investigation with the three orientation of the external magnetic field: (i) the field is perpendicular to the sample plane ($\theta = 0°$); (ii) the field is directed at 45 degree to the sample plane along the short side of the rectangle cell ($\theta = 45°$, $\phi = 0°$); (iii) the field is directed at 45 degree to the sample plane along the long side of the rectangle cell ($\theta = 45°$, $\phi = 90°$). The results of this measurements for $T = 4.2$ K are represented in Figs. 2 and 3.

The difference in the magnetization curves indicates the collective behavior of the system, which is the result of the dipole-dipole interaction between particles. The hysteresis if the field directed at $\theta = 45°$, $\phi = 0°$ (Fig. 2) is the attribute of the easy axis of the magnetization which is directed along the short side of the rectangle cell. The remanent magnetization is absent in this case. The curve for $\theta = 45°$, $\phi = 90°$ (Fig. 3) have hysteresis

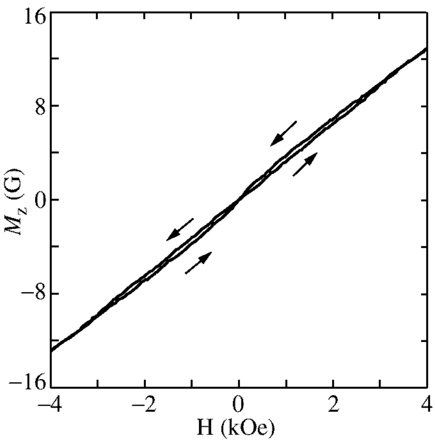

Fig. 2. The dependence of M_z on the magnetic field with $\theta = 45°$, $\phi = 0°$.

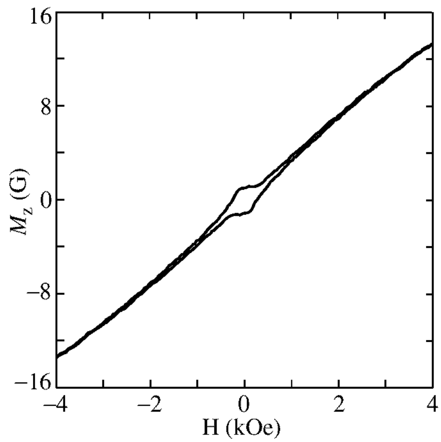

Fig. 3. The dependence of M_z on the magnetic field with $\theta = 45°$, $\phi = 90°$.

in the weak magnetic field with the remanent magnetization which is approximately 0.05 of the saturation magnetization, one equals 35 G. The remanemt magnetization apparently is reasoned by the nonuniform states which are appear in this case.

Now we study the applicability of fullerides technology for creation nanoparticles of another metals and semiconductors (GaAs, InSb, Ge, Si, Co, Cr etc). The details of this investigation we'll publish elsewhere.

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